(s) at one time; forming the upper electrode; and conducting heat-treatment
in an oxygen atmosphere at about 550.degree. C. for about 60 minutes.

(91) The crystallizing heat-treatment may be conducted either as
batch-crystallization for collectively heat-treating the film deposited to a
desired thickness by repeating the applying and drying steps several times, or
as a crystallization process for heat-treating the films on a film-by-film
basis after every applying and drying step. Moreover, the time for the
heat-treatment is not specifically limited. The heat-treatment may be
conducted for several minutes to several hours in a diffusion furnace, or may
be conducted for several tens of seconds to several minutes by RTA Rapid
Thermal Annealing). In short, the time for the heat-treatment is determined so
that sufficient crystallization can be achieved in respective heat-treatment
processes.

(92) In general, heat-treatment for crystallizing an oxide must be conducted
in an oxygen atmosphere due to its requirement to supply a sufficient amount of
oxygen. On the other hand, in the methods such as a sol-gel method and an MOD
method, a large amount of oxygen is contained in the raw materials such as
metal alkoxide and salt. Therefore, crystallization can be conducted even in
an inert atmosphere such as nitrogen or argon. However, in order to improve
the ferroelectric characteristics and suppress a leakage current, it is
preferable to conduct heat-treatment at about 400.degree. C. to about
650.degree. C. after the formation of the upper electrode.

(93) According to the MOCVD method, the ferroelectric film is formed as

L Number	Hits	Search Text	DB	Time stamp
1		crystallizing with (pzt or ferroelectric) with (Ar or argon) with oxygen	USPAT; US-PGPUB	2003/05/01 10:36
2		crystallizing with (pzt or ferroelectric) with (Ar or argon)	USPAT; US-PGPUB	2003/05/01 10:36
3	130	crystallizing with (pzt or ferroelectric)	USPAT; US-PGPUB	2003/05/01 10:36
4	84	crystallizing with (pzt or ferroelectric) and oxygen and (ar or argon or nitrogen)	USPAT; US-PGPUB	2003/05/01 10:37
5	81	((crystallizing with (pzt or ferroelectric)) and oxygen and (ar or argon or nitrogen)) not (crystallizing with (pzt or ferroelectric) with (Ar or argon))	USPAT; US-PGPUB	2003/05/01 10:37
6	73	(((crystallizing with (pzt or ferroelectric)) and oxygen and (ar or argon or nitrogen)) not (crystallizing with (pzt or ferroelectric) with (Ar or argon))) and capacitor	USPAT; US-PGPUB	2003/05/01 11:30
7	3623	438/3,240,253,381,396.ccls.	USPAT; US-PGPUB	2003/05/01 11:47
8	786	438/3,240,253,381,396.ccls. and capacitor and ferroelectric	USPAT; US-PGPUB	2003/05/01 11:47
9	460	(438/3,240,253,381,396.ccls. and capacitor and ferroelectric) and @ad<=20000417	USPAT; US-PGPUB	2003/05/01 11:47
10	2194	257/295,303,306,310.ccls.	USPAT; US-PGPUB	2003/05/01 11:47
11	745	257/295,303,306,310.ccls. and capacitor and ferroelectric	USPAT; US-PGPUB	2003/05/01 11:47
12	476	(257/295,303,306,310.ccls. and capacitor and ferroelectric) and @ad<=20000417	USPAT; US-PGPUB	2003/05/01 11:47

US-PAT-NO: 6201271

DOCUMENT-IDENTIFIER: US 6201271 B1

TITLE: Semiconductor memory device
prevented from deterioration
due to activated hydrogen

---------- KWIC ---------

As an electrode material of the ferroelectric capacitor,
platinum has widely
been used for both the upper electrode and the lower
electrode for such a
reason that it has a resistivity to a high-temperature
oxidative atmosphere for
crystallizing the ferroelectric material. As a
ferroelectric material to be
used for the ferroelectric capacitor, attention is focused
on $SrBi.sub.2$
$Ta.sub.2$ $O.sub.9$ (SBT) and $Bi.sub.4$ $Ti.sub.3$ $O.sub.12$ (BIT)
that have excellent
fatigue properties and are able to be operated at low
voltage as compared with
$PbZr.sub.x$ $Ti.sub.1-x$ $O.sub.3$ (PZT) having been examined to
the detail, and the
former substances are under elaborate examination.

According to an embodiment of the present invention,
hydrogen sintering for
the final recovery can be performed without deteriorating
the ferroelectric
characteristic nor the highly dielectric characteristic.
Both the upper
electrode and the ferroelectric material or the highly
dielectric material are
constructed of oxide materials, and therefore, the elements
and **oxygen** atoms
constituting the ferroelectric material or the highly
dielectric material
scarcely move even in the heat treatment in the subsequent
production stage or
aging during use, for which the fatigue characteristic of

the ferroelectric
material and the reduction with time in dielectric constant
of the highly
dielectric material are also improved.

FIG. 4 is a sectional view of the plasma TEOS film of
FIG. 3 improved in
shape by **argon** sputtering;

Further, in order to improve the adherence of the formed
lower electrode,
annealing was effected for 30 minutes in **nitrogen** at a
temperature of
600.degree. C. in an electric furnace.

Subsequently, the PZT film 11 was formed to a film
thickness of 2000 .ANG.
by the sol-gel method. The above PZT film forming method
is performed by
firstly dissolving lead acetate, titanium isopropoxide and
zirconium
isopropoxide into a solvent of 2-methoxyethanol so that the
ratio of
Pb:Ti:Zr=100:52:48 thereby forming a sol-gel material
solution, coating this
material solution on a silicon wafer formed to the lower
electrode by means of
a spinner rotating at a rotating speed of 3000 rpm, drying
the wafer at a
temperature of 150.degree. C. for 10 minutes in the
atmospheric air and
thereafter performing temporary baking at a temperature of
410.degree. C. for
30 minutes in the atmospheric air. The coating is repeated
three to five times
so that the desired film thickness of 2000 .ANG. is
achieved. Subsequently, a
heat treatment for crystallization is performed by the RTA
(Rapid Thermal
Annealing) method at a temperature of 650.degree. C. for
30 seconds in an
atmosphere of a mixture of **nitrogen and oxygen**. In this
stage, the flow rates
of **nitrogen and oxygen** were set so that **nitrogen** flow rate:
oxygen flow
rate=4:1.

Next, the PZT film 11 and the lower electrode 10 were processed to a size
of, for example, about 2.6 .mu.m.times.2.6 .mu.m and 3.0 .mu.m.times.3.0 .mu.m
by the dry etching method, respectively. Subsequently, the titanium oxide film
12 was formed by the RF magnetron reactive sputtering method to a thickness of
250 .ANG. as a diffusion preventing layer of the elements constituting the
ferroelectric capacitor. The ozone TEOS film 13 was formed as a second
interlayer insulating film by the CVD method, and the titanium film 14 was
further formed by the RF magnetron sputtering method to a thickness of 300
.ANG. as a layer for adhesion to the upper electrode of the capacitor to be
formed on it. Next, a hole of, for example, about 1.8 .mu.m.times.1.8 .mu.m
was formed by the dry etching method through the titanium film 14, the second
interlayer insulating film 13 and the titanium oxide film 12 above the
ferroelectric capacitor, so that a contact hole was opened up to the surface of
the PZT film 11. The PZT film 11 was damaged by plasma exposure due to the dry
etching. In order to recover this, a heat treatment was performed at a
temperature of 500.degree. C. for 30 seconds in **oxygen** by the RTA (Rapid
Thermal Annealing) method.

The elemental composition ratio of the formed alloy oxide film 15 of
platinum and rhodium was expressed by the ratio of platinum: rhodium
oxygen=70:15:15. The film formation was performed by the RF magnetron reactive
sputtering method while adjusting the total gas flow rate so that the reaction
chamber comes to have a pressure of 10 mTorr at a gas flow rate of
argon:oxygen=2:1. If the rhodium content increases with respect to the
composition ratio of platinum to rhodium, then the

crystallinity of platinum
having a peak of (111) becomes worse, and this is
disadvantageous because a
volumetric expansion will be significant during heat
treatment in the
subsequent process. Therefore, the rhodium content must be
not greater than 20
percent in terms of the composition ratio thereof to
platinum. Furthermore,
unless a rhodium content of not smaller than 10 percent is
achieved, no
sufficient oxide results, so that the effect of platinum
atoms for activating
hydrogen cannot be suppressed. Therefore, rhodium must be
not smaller than 10
percent and not greater than 20 percent in terms of the
composition ratio
thereof to platinum. Furthermore, for the same reason as
above, the **oxygen**
content relative to all the elements must be not smaller
than 10 percent and
not greater than 17 percent.

Next, the titanium nitride film 16, the alloy oxide film
15 of platinum and
rhodium and the titanium film 14 were processed into a
drive line shape by the
dry etching method using chlorine gas. As stated before,
the PZT film is also
indirectly damaged by plasma exposure due to this dry
etching. Therefore, for
the purpose of recovering this, a heat treatment was
performed at a temperature
of 550.degree. C. for 30 seconds in **oxygen** by the RTA
method.

In view of the above, the plasma TEOS film was firstly
formed to a thickness
of 3000 .ANG. as the third interlayer insulating film.
Since an overhung
shape (see the reference character D in FIG. 3) appeared
even at this degree of
film thickness, the shape was improved as shown in FIG. 4
by reverse sputtering
using **argon,** and thereafter the ozone TEOS film was formed
to a thickness of
7000 .ANG.. This film contained a certain amount of

moisture, and therefore,
the plasma TEOS film was formed to a thickness of 3000
.ANG. for the
prevention of the upward diffusion of moisture. The
contact hole was formed in
this place and the aluminum lead electrode 18 extending
from the source/drain
region was formed by the DC magnetron sputtering method.

   Furthermore, a similar capacitor was formed of platinum
for the capacitor
upper electrode by the prior art technique, and the
capacitor to which the
present invention is applied and the prior art capacitor
were concurrently
subjected to a heat treatment for 10 minutes in an
atmosphere of five percent
of hydrogen and 95 percent of **nitrogen** while changing the
heat treatment
temperature, and the residual dielectric polarization
values were measured
after the heat treatment. As shown in FIG. 6, it was
discovered that the
residual dielectric polarization value of the capacitor
using the prior art
technique was reduced at and around the temperature of
180.degree. C. and the
residual dielectric polarization value of the capacitor of
the present
invention was not reduced until the temperature of
430.degree. C.

   FIG. 3 shows the second embodiment of the present
invention, where the same
components described with reference to FIG. 1 are denoted
by the reference
numerals and no description is provided for them. In FIG.
8 are shown a
tungsten plug 19 formed for making contact of the
source/drain region 5 with
the capacitor lower electrode, an alloy film 20 of platinum
and rhodium formed
on the tungsten plug, an alloy oxide film 21 of platinum
and rhodium formed as
a diffusion barrier and **oxygen** preventing film, a platinum
film 22 for
improving the morphology of the ferroelectric film, and a

titanium oxide film
12 that serves as a diffusion preventing layer of elements of the ferroelectric
film 23 formed on the lower electrode 22. In FIG. 8 are also shown a
SrBi.sub.2 Ta.sub.2 O.sub.9 (SBT) film 23 formed on the lower electrode 22 and
an alloy film 24 of platinum or platinum and rhodium for a drive line
interconnection.

   Subsequently, tungsten is buried in the contact hole by the CVD method, and
thereafter the surface is flattened by the CMP (Chemical Mechanical Polishing)
method, thereby forming the tungsten plug 19. The alloy film 20 of platinum
and rhodium was formed to a film thickness of 700 .ANG. on this tungsten plug
19 by the DC magnetron sputtering method, thereafter alloy oxide film 21 of
platinum and rhodium to a film thickness of 300 .ANG. on the alloy film 20 by
the DC magnetron reactive spattering method, and the platinum film 22 was
further formed to a film thickness of 500 .ANG. by the DC magnetron sputtering
method. The elemental composition ratio of the formed alloy film of platinum
and rhodium was expressed by the ratio of
platinum:rhodium=80:20. The
elemental composition ratio of the alloy oxide film of platinum and rhodium was
expressed by the ratio of platinum:rhodium:oxigen=70:15:15. The film formation
was performed by the magnetron reactive sputtering method while adjusting the
total gas flow rate so that the reaction chamber come to have a pressure of 10
mTorr at a gas flow rate of **argon:oxygen**=1:1.

   Next, a material solution of SrBi.sub.2 Ta.sub.2 O.sub.9 (SBT) was coated on
this lower electrode by a spinner rotating at a rotating speed of 3000 rpm by
the MOD (Metal Organic Deposition) method and dried at a temperature of

250.degree. C. for five minutes. First baking was performed at a temperature
cf 600.degree. C. for five minutes in an **oxygen** atmosphere at the atmospheric
pressure, and subsequently second baking, i.e. a heat treatment for
crystallization, was performed in an **oxygen** atmosphere at a temperature of
80 .degree. C. for five minutes by the RTA method. The processes from the
coating to the heat treatment for crystallization were repeated three to five
times so that an SBT film 23 came to have the desired film thickness of 2000
.ANG.. The forming method may be the sputtering method or the MOCVD (Metal
Organic CVD) method besides the MOD method. In this case, when the composition
ratio of rhodium increases in the alloy film of platinum and rhodium, the
crystallinity of platinum having a peak of (111) and the film flatness become
worse, so that the leak current characteristic of the ferroelectric film that
lies in the upper layer deteriorates. Therefore, rhodium must have an element
ratio of not greater than 80 percent relative to platinum. If the rhodium
content is small in the alloy oxide film of platinum and rhodium, no sufficient
oxide film results to reduce the **oxygen** blocking effect, so that the surface of
the tungsten plug is oxidized during annealing in the presence of **oxygen**,
consequently causing an electrical defective continuity. Therefore, rhodium
must have an element ratio of not smaller than 10 percent relative to platinum
in the alloy oxide film of platinum and rhodium.

   Next, the titanium nitride film 16 and the film 24 that is alloy film of
platinum and rhodium or platinum, and the titanium 14 were processed into a
drive line shape by the dry etching method using chlorine gas. The SBT film is
also indirectly damaged by plasma exposure due to this dry

etching. Therefore,
for the purpose of recovering this and improving the leak
characteristic of the
ferroelectric capacitor, a heat treatment was performed in
an **oxygen** atmosphere
at a temperature of 800.degree. C. for 15 minutes.

    Next, using a material of TEOS (tetraethoxysilane), the
third interlayer
insulating film 17 comprised of a plasma TEOS film of 3000
.ANG., an ozone TEOS
film of 7000 .ANG. and a plasma TEOS film of 3000 .ANG.
was formed. In
general, the plasma TEOS film has a small moisture content
in the film,
however, it has a great amount of hydrogen content. The
plasma TEOS film also
tends to have a shape as indicated by the reference
character D in FIG. 3, when
its thickness is increased. On the other hand, the ozone
TEOS film has a small
amount of hydrogen content in the film, however, it has a
great amount of
moisture and a groundwork dependency. Consequently, the
film thickness of the
interlayer insulating film varies as shown in FIG. 2. In
view of the above,
the plasma TEOS film was firstly formed to a thickness of
3000 .ANG. as the
third interlayer insulating film. Since an overhung shape
(see the reference
character D in FIG. 3) appeared even at this degree of film
thickness, the
shape was improved as shown in FIG. 4 by reverse sputtering
using **argon,** and
thereafter the ozone TEOS film was formed to a thickness of
7000 .ANG.. This
film contained an increased amount of moisture, and
therefore, the plasma TEOS
film was formed to a thickness of 3000 .ANG. for the
prevention of the upward
diffusion of moisture. The contact hole was formed in this
place and the
aluminum lead electrode 18 extending from the source/drain
region 5 was formed
by the DC magnetron sputtering method.

US-PAT-NO: 6287637

DOCUMENT-IDENTIFIER: US 6287637 B1

TITLE: Multi-layer approach for optimizing
ferroelectric film

                      performance

---------- KWIC ---------

    FIGS. 2(a), (b), (c), and (d) show the comparison of
switched charge,
V(90%), switched charge loss, and opposite state charge
aging rate for the two
types of PZT films, one of which is annealed in an **oxygen**
ambient atmosphere,
the other of which is annealed in a combined ambient
atmosphere of **argon and**
oxygen; and

    In the preferred embodiment, a Gryphon Sputtering
Deposition Tool is used.
All layers 14, 16, and 18 are deposited at the same
temperature (Room
Temperature) and in the same sputter ambient environment
(**Argon**). The sputter
conditions for the nucleation layer 14 are 750 watts at an
18 mTorr pressure to
produce a film between 50 and 100 Angstroms thick with
approximately 30% excess
lead. The bulk layer 16 is deposited at 1000 watts at a 2
mTorr pressure to
build up the remaining film thickness with an excess lead
content of about
15-20%. If an optional cap layer 18 is employed to enhance
the top electrode
2 interface characteristics, the bulk layer 16 thickness
is reduced by the
additional thickness of the cap layer 18. The cap layer 18
is between 200 and
300 Angstroms thick and varies between 25 and 35% excess
lead. The sputter
conditions for producing the cap layer 18 lead contents are

750 watts at a 10
mTorr pressure for 25% excess lead and 550 watts at an 18
mTorr pressure for
35% excess lead.

According to another method of the present invention, a specific anneal
sequence is utilized after PZT deposition to control the crystalline texturing
of the film, and by doing so, enhancing low voltage performance. In general,
"texturing" is defined as preferred orientation and grain structure. This is
accomplished by modifying the lead content in the PZT film to take advantage of
specific phase formations that enhance PZT texturing. A multi-layer PZT is
utilized to obtain a specific lead profile, with an associated anneal sequence
to take advantage of that profile. The anneal sequences involve a two step
process wherein a first step utilizes a low temperature **argon** ambient anneal to
drive the formation of a platinum-lead and platinum-titanate intermetallic
phases at the bottom electrode interface and a second step utilizes an **oxygen**
anneal to complete the PZT crystallization process.

The multi-layer processing of the present invention is used because
considerably more lead is required near the bottom electrode interface to
supply the platinum-lead intermetallic layer; this high level of lead cannot be
sustained in the bulk of the PZT film without an adverse impact on the kinetics
driving crystal formation. The **argon** ambient anneal is used in the first step
to prevent over saturation of the bottom electrode interface with **oxygen**.
Excessive **oxygen** shuts down the desirable platinum-lead phase and favors an
undesirable lead oxide (PbO) phase, which has a detrimental impact on PZT
texture. By using the **argon** sequence of the present invention to establish the

platinum-lead and platinum titanate intermetallic phases, the energy required
to produce a favorable texture during the **oxygen** anneal sequence can be
reduced. Since the required energy is reduced, the stress/strain relationships
on the lattice are reduced and the crystal forms along preferred orientations
dictated by the nucleation foundation layer. Depending upon the PZT dopants
used, the **argon** anneal generates a strong <111> orientation preference or
a mixed texturing of <001> and <111> orientations. In particular,
the quality of the <001> texturing directly influences the low voltage
performance of the film. An additional benefit of reducing the energy
requirements for the anneal is the conservation of lead in the bulk of the
film. This conservation of lead enhances fatigue performance.

The **argon and oxygen** anneal sequence of the present invention can be
modified by the addition of certain dopant materials to further enhance low
voltage performance. A PZT film can be doped with lanthanum, calcium, and
strontium dopants to achieve low voltage ferroelectric operation. Operation as
low as three volts has been demonstrated, and the potential exists for
operation at even lower voltages less than three volts. In addition, the **argon
and oxygen** anneal described herein can be applied to other ferroelectric
compositions as well as with other electrode structures and materials.

Utilizing the multi-layer PZT structure in conjunction with the two step
anneal process enhances ferroelectric performance by establishing sufficient
lead in the nucleation layer to adequately establish the intermetallic phases
of lead platinum (Pb--Pt) and lead titanate (Pb--Ti).

These phases provide the foundation and seeding for proper PZT nucleation with orientation for optimum ferroelectric performance. The nucleation layer is kept thin (about 100 to 200 Angstroms) and lead rich (30%.+-.5%) and provides the lead necessary to complete the phase interactions for the time and temperature window of the **argon** portion of the anneal. The **argon** anneal step is desirable to enhance the Pb--Pt and Pb--Ti interactions without the presence of **oxygen**. Typically, **oxygen**-only anneals overrun these interactions with the formation of PbO (lead oxide), which disrupts the preferred phase formations. The PbO formation is detrimental to preferred crystal orientation (<100> and <110> mixed orientations). After the **argon** portion of the anneal, the foundation is set for good crystal orientation, <111> and <001>, but the lattice remains **oxygen** deficient. The second anneal is done in an **oxygen** ambient atmosphere to complete the crystal formation, which is now driven by the foundation established with the **argon** anneal. The **oxygen** anneal fills the **oxygen** vacancies and completes the crystalline structure for the bulk of the film. The bulk of the PZT film can not be as lead rich (bulk layer lead =15%.+-.5%) as the nucleation layer or excessive amounts of PbO would be generated during the **oxygen** anneal and again disrupt preferred crystal orientation in the bulk of the film.

Step 1 (**Argon** Anneal)

Argon ambient atmosphere;

Step 2 (**Oxygen** Anneal)

Oxygen ambient atmosphere;

After annealing, the wafer receives a top electrode deposition (1750
Angstroms of platinum), patterning and etch followed by a furnace anneal
process at 650.degree. C. for 60 minutes in an **oxygen** ambient atmosphere, at
which point the wafer is ready for electrical testing.

The main object of this embodiment of the present invention is the
application of reduced O.sub.2 partial pressure ambient during PZT thin film
crystallization. **Crystallizing PZT** thin films in reduced O.sub.2 partial
pressure ambient results in better ferroelectric performance, cross wafer
uniformity and wafer-to-wafer repeatability compared with pure O.sub.2
crystallization ambient.

Ferroelectric PZT [Pb(Zr,Ti)O.sub.3] thin film is one of the key components
in FRAM.RTM. technology. After being deposited on a substrate, the PZT thin
film needs to be annealed at elevated temperature, such as 600.degree. C., to
form a polycrystalline thin film with a complex perovskite structure. Since
PbO is very volatile at high temperature, say above 500.degree. C., the lead
loss in the area close to the surface of the PZT film is higher than that in
the bulk of the PZT film, resulting in a non-uniform distribution of lead in
the direction of the thickness of the film. Adding excess lead in the PZT film
before crystallization may compensate the lead loss in the surface area during
high temperature anneal and form the perovskite phase. However, the lead
content in the bulk of the PZT film may be too high. It may be difficult for
lead to diffuse out of the film as the perovskite phase may block the migration
of lead cations. Since the Pb--O bonding in PbO is much weaker than that in a
perovskite structure, it is therefore more difficult for

lead cations to
migrate through a perovskite phase. One way to increase
the mobility of lead
cations in a perovskite phase is to generate **oxygen**
vacancies in the perovskite
structure. It is known that the perovskite structure can
tolerate vacancy
concentration up to 20%. It is therefore possible to
crystallize as-sputtered
PZT film in a reduced O_2 partial pressure ambient so
that the perovskite
structure can still form but with a large amount of O_2
vacancies embedded
in the structure. O_2 vacancies provide effective
paths for lead cations
to migrate in the film during high temperature sintering,
giving rise to a more
uniform lead distribution and more homogeneous formation of
a perovskite phase.

There are two ways to generate a reduced O_2 partial
pressure ambient.
One is to use vacuum environment and flow a small amount of
O_2 gas into
the annealing chamber. Another way, according to the
present invention, is to
simultaneously flow O_2 and another type of gas that
will not react with
PZT film, such as **argon,** into the annealing chamber during
high temperature
crystallization. Method one requires an expensive pumping
system and a good
vacuum control system. Method two according to the present
invention only
requires mass flow controllers and a reasonable seal of the
annealing chamber.

The assignee of the present invention, Ramtron
International Corp. has used
Argon rich ambient gas to crystallize PZT films for FRAM
applications and parts
containing PZT film annealed in an **Argon/oxygen** ambient
atmosphere have been
built and evaluated. The **oxygen** partial pressure in
Ramtron's RTA (Rapid
Thermal Anneal) chamber is in the range of 10^{-4} to 100
Torr.

Experiments have been conducted to evaluate the ferroelectric performance of
PZT films crystallized in the **Argon** rich ambient according to the present
invention (**Ar** O.sub.2 mixture followed by O.sub.2 anneal--herein **Ar**/O.sub.2
then O.sub.2), and for comparison, O.sub.2 only ambient followed by O.sub.2
anneal--herein O.sub.2 then O.sub.2. FIGS. 2(a), (b), (c), and (d) show the
comparison of switched charge V(90), switched charge loss, and opposite state
charge aging rate for the two types of PZT films it can be seen that the PZT
films crystallized in the combined **Argon** and O.sub.2 ambient of the present
invention (i.e., **Ar**/O.sub.2 then O.sub.2) indeed show better ferroelectric
performance compared with samples crystallized in the O.sub.2 ambient (i.e.,
O.sub.2 then O.sub.2) (that is, higher switch charge (Q.sub.SW), lower V.sub.90
?, lower Q.sub.SW loss @ 10.sup.9 cycles, and comparable opposite state
switched charge aging rate).

FIG. 3 is a diagram of an RTA (Rapid Thermal Anneal) chamber for annealing a
PZT wafer according to the present invention. An RTA chamber 32 includes
heating coils 36 powered by a heating control unit 44. The RTA chamber 32
further includes a substrate or platform 38 for supporting a PZT wafer 40. A
thermocouple 42 provides feedback to heating control unit 44. The RTA chamber
32 further includes a door 34 for introducing the wafer to the chamber.
Annealing gasses are provided through **oxygen** cannister 46, **nitrogen** cannister
48, and **oxygen** cannister 50, which are introduced to the RTA chamber 32 under
control of valves 52, 54, and 56, as required.

It is important to note that the combined **argon and oxygen** anneal of the

present invention can be used on either single layer, bi-layer, or tri-layer
PZT films. Also, other inert gasses besides **argon** can be used, such as
nitrogen or helium, or the like. The exact temperature and partial pressure of
oxygen can be changed as required. A second anneal in **oxygen** can also be
performed.

Having described and illustrated the principle of the invention in a
preferred embodiment thereof, it is appreciated by those having skill in the
art that the invention can be modified in arrangement and detail without
departing from such principles. For example, if desired, the method of
fabricating a ferroelectric multi-layer thin film according to the present
invention can be modified to include only a single PZT layer, followed by the
steps of annealing the single PZT layer in an **argon** ambient atmosphere, and
then annealing the single PZT layer in an **oxygen** ambient atmosphere.
Improvements in performance will still be obtained, even though a single PZT
layer is used. We therefore claim all modifications and variations coming
within the spirit and scope of the following claims.

annealing the PZT film in a combined **argon and oxygen** ambient atmosphere
during PZT thin film crystallization; and

thereafter annealing the PZT film in an **oxygen** ambient atmosphere.

8. The method of claim 7 in which the second gas is **argon**.

9. The method of claim 7 in which the second gas is **nitrogen**.

12. The method of claim 7 in which the **oxygen** partial pressure in the

annealing chamber during said high temperature
crystallizaton is in the range
of 10.sup.-4 to 100 Torr.